

## The New Milky Way: a wide-field survey of optical transients near the Galactic plane

Kirill Sokolovsky,<sup>1,2</sup> Stanislav Korotkiy,<sup>3</sup> and Alexandr Lebedev<sup>4</sup>

<sup>1</sup>*Astro Space Center of Lebedev Physical Institute, Russian Academy of Sciences, Profsoyuznaya Str. 84/32, 117997 Moscow, Russia*

<sup>2</sup>*Sternberg Astronomical Institute, Moscow State University, Universitetskii pr. 13, 119992 Moscow, Russia*

<sup>3</sup>*“Ka-Dar” astronomy foundation, Kuzminki, P.O. Box 82, 142717 Moscow region, Russia*

<sup>4</sup>*Institute of Astronomy, Russian Academy of Sciences, Pyatnitskaya Str. 48, 119017 Moscow, Russia*

**Abstract.** Currently, it may take days for a bright nova outburst to be detected. With the few exceptions, little is known about novae behaviour prior to maximum light. A theoretically-predicted population of ultra-fast novae with  $t_2 < 1^d$  is evading observational discovery because it is not possible to routinely organize fast follow-up observations of nova candidates. With the aim of brining the detection time of novae and other bright ( $V < 13.5$ ) optical transients from days down to hours or less, we develop an automated wide-field ( $8^\circ \times 6^\circ$ ) system capable of surveying the whole Milky Way area visible from the observing site in one night. The system is built using low-cost mass-produced components and the transient detection pipeline is based on the open source VaST software. We describe the instrument design and report results of the first observations conducted in October–November 2011 and January–April 2012. The results include the discovery of Nova Sagittarii 2012 No. 1 as well as two X-ray emitting cataclysmic variables 1RXS J063214.8+25362 and XMMSL1 J014956.7+533504. The rapid detection of Nova Sagittarii 2012 No. 1 enabled us to conduct its X-ray and UV observations with *Swift* 22 hours after discovery ( $\approx 31$  hour after the outburst onset). All images obtained during the transient search survey are available online.

### 1. Introduction

A transient detection survey is characterized by its depth, area and cadence. Most of the current optical surveys are either deep/low-cadence (Lipunov et al. 2007; Drake et al. 2009; Minniti et al. 2010; Kaiser et al. 2010; Hadjiyska et al. 2013) or very shallow/very high-cadence (Burd et al. 2005; Beskin et al. 2010; Urata et al. 2010). The gap between the two extremes (a medium-depth/medium-cadence survey) is covered by numerous transiting exoplanets search experiments (e.g., Street et al. 2003; Alonso et al. 2004; McCullough et al. 2005; Pepper et al. 2007; Bakos et al. 2009) which typically lack real-time transient detection capability and amateur nova searches. Two notable examples of wide-field medium-depth surveys capable of detecting transients are ASAS-3 (Pojmański 2001) and ROTSE-I/NSVS (Lee et al. 1998; Woźniak et al. 2004), unfortu-

nately ROTSE-I has completed its observations in 2001 and ASAS-3 has not reported detection of a transient source since 2011. There are, however, good reasons to pay more attention to transient search in this region of survey parameter space.

Potential targets for a medium-cadence (about one visit per night) optical survey in the 9–14<sup>m</sup> range include classical and symbiotic novae, cataclysmic variables (dwarf novae) and other X-ray binaries, FU Ori-type flares, brightest microlensing events (Mikolajewski et al. 2006), intriguing “anti-transients” characterized by a dramatic drop in star’s brightness not related to an eclipse or R CrB-type dust formation event (Denisenko et al. 2012), other variable stars, bright blazar flares. Rapid detection of extreme events such as star-star (Tylanda & Soker 2006; Tylanda et al. 2011) and star-planet (Metzger et al. 2012) mergers or a Galactic supernova (Carlton et al. 2011) would be of crucial importance for their investigation.

The expected classical novae rate in the Galaxy is  $\sim 35 \text{ yr}^{-1}$  (Shafter 1997; Darnley et al. 2006), but the actual discovery rate<sup>1</sup> is  $\sim 10 \text{ yr}^{-1}$ . While some are missed due to their Sun proximity, a number of potentially detectable outbursts are missed because current searches lack time coverage and depth. If a typical outburst detection time could be shortened from days down to a few hours or less, it would provide obvious scientific benefits. Nova detection before its maximum light ensures accurate determination of its maximum magnitude and decline rate ( $t_2$ ,  $t_3$ ) and the values derived from them. Better constrained outburst onset time would aid interpretation of unusual cases such as  $\gamma$ -ray-bright novae (Abdo et al. 2010; Cheung et al. 2012a,b). Rise time distribution of novae could be studied if accurate outburst onset times are known for many of them. A theoretically-predicted population of ultra-fast novae with  $t_2 < 1^d$  is evading detection because it is not possible to routinely organize fast follow-up observations of nova candidates.

We describe the “New Milky Way” (NMW) – an automated system capable of surveying the whole Milky Way area visible from the observing site during one night down to magnitude  $V < 13.5$ . The system is built using low-cost components and the transient detection pipeline is based on open source software. The survey strategy and data reduction pipeline are designed with the aim to inform the community and enable multi-wavelength follow-up of detected transients a few hours after they are imaged.

## 2. The New Milky Way camera

The transient detection system consists of a wide-field survey camera: an  $f = 135 \text{ mm}$   $f/2.0$  telephoto lens attached to an unfiltered ST8300M CCD installed on a HEQ-5 Pro robotic mount, a Windows-based computer controlling the mount and the camera through a custom-made software developed by Vasily Vershinin and a Linux-based data-reduction computer. The system is operated from an altitude of 2000 m by Ka-Dar Observatory at Karachay-Cherkessia (MPC code C32) at the Russia’s North Caucasus mountains. The system parameters are summarized in Table 1.

For data reduction we choose object detection rather than image subtraction, because the former approach is computationally more efficient and provides better photometric accuracy despite being less sensitive in crowded fields (Schmidt 2012). The transient detection pipeline is implemented as a BASH script controlling the VaST soft-

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<sup>1</sup>[http://www.cbat.eps.harvard.edu/nova\\_list.html](http://www.cbat.eps.harvard.edu/nova_list.html)

Table 1. The New Milky Way survey parameters.

Optics:	Canon 135 mm f/2.0	Accuracy at $V \sim 11$ :	$\sim 0^{\text{m}}1$ absolute
CCD camera:	SBIG ST-8300M (blue-sensitive chip)		$0^{\text{m}}05$ internal
Image size:	3352×2532 pix	Images per field:	2 or 3 per night (dithering)
Optical filter:	none	Stars per frame:	$\sim 20000$
Equatorial mount:	HEQ-5 Pro	Images per night:	$\sim 200$
Field of view:	$8^\circ \times 6^\circ$	Milky Way imaging time:	5 hr (January) 10 hr (April)
Pixel scale:	8.4''/pix	Processing time:	up to 7 hr/night
Exposure time:	20–40 sec	Results inspection time:	up to 4 hr/night
Limiting magnitude:	$V \sim 14.5$		
Transient detection limit:	$V \sim 13.5$		



Figure 1. The New Milky Way camera (left) and an example image (right; fraction of the full frame) showing the Lagoon (M8) and Trifid (M20) nebulae region in Sagittarius.

ware<sup>2</sup> (Sokolovsky & Lebedev 2005) which performs the following steps. (i) Star detection and circular aperture photometry using SExtractor (Bertin & Arnouts 1996). (ii) Cross-matching the lists of stars detected on reference (first-epoch) and second-epoch images. Transient candidates are identified as objects detected on all second-epoch images that were either not detected or were at least  $1^{\text{m}}$  fainter on the reference image. The second criterion is needed to identify a low-amplitude flare or a high-amplitude flare of a faint object that is blended with a brighter one visible on the reference image. Small movement of the telescope between images (dithering) is used to reject CCD artifacts. (iii) Images are plate-solved using the Astrometry.net<sup>3</sup> software (Lang et al. 2010; Hogg et al. 2008) and celestial positions of the detected stars obtained. (iv) The instrumental magnitude scale is calibrated using V magnitudes of unsaturated Tycho-2 (Høg et al. 2000) stars in the field of view.

<sup>2</sup>VaST is the open source software available at <http://scan.sai.msu.ru/vast/>

<sup>3</sup>see <http://astrometry.net/>

The main problem of our transient detection system is that it currently lacks an automated enclosure. While being able to perform observations automatically, it still has to be set up, started and stopped manually. Thus, observing time is limited by the availability of a qualified observer on site.

### 3. Results

**Nova Sagittarii 2012 No. 1.** Nova Sgr 2012 No. 1 (PNV J17452791–2305213, 17:45:28.02 –23:05:23.1  $\pm 0''.1$ , J2000, Korotkiy et al. 2012) was detected on the NMW images obtained on 2012 April 21.0112 UT at  $V = 9.6$  and reported through the CBAT Transient Objects Confirmation Page (TOCP<sup>4</sup>). First independent confirmation images were obtained on April 21.654 UT by J. Seach (Australia) with a 50 mm f/1.0 lens attached to a DSLR camera. The pre-discovery images obtained on April 20.84032 UT at Xingming observatory (near Urumqi, China; MPC code C42) showing the object at  $V = 10.2$  were later reported. It was discovered by A. Watson that the outburst was recorded in detail by the inner Heliospheric Imager telescope on the STEREO *Behind* spacecraft<sup>5</sup>. The STEREO-B observations allow to estimate the outburst onset time as April  $\sim 20.6$  UT. Availability of pre-discovery images by Xingming obs. and STEREO-B obtained hours before the NMW images highlight the challenges of rapid information extraction from the data.

A *Swift* ToO observation was performed on April 21.912, 22 hours after discovery and  $\approx 31$  hour after the outburst onset (Sokolovsky et al. 2012). To the best of our knowledge, this is the fastest X-ray follow-up observation of an optically-detected nova. While the first and the two following (April 25.7 and 26.1, Nelson et al. 2012b) observations detected no X-ray emission, observations on May 10 revealed hard X-ray emission from the nova shell (Nelson et al. 2012a). Optical spectroscopy allows one to classify the object as a fast He/N type nova with expansion velocity up to 6500 km/s (Korotkiy et al. 2012; Esipov et al. 2012). Nova Sgr 2012 No. 1 was also the target of radio (Nelson et al. 2012b) and infrared observations (Raj et al. 2012; Varricatt et al. 2012).

**1RXS J063214.8+25362.** A previously undetected 13<sup>m</sup>1 source appeared at 06:32:13.082 +25:36:22.68 ( $\pm 0''.1$ , J2000) on 2012 January 24 gradually brightening to 12<sup>m</sup>6 by January 27 (Korotkiy & Sokolovsky 2012b). The object was below the detection limit on January 21. It is located 24'' from an unidentified X-ray source 1RXS J063214.8+253620 listed in the ROSAT All Sky Survey Faint Source Catalog (Voges et al. 2000) and is likely associated with it. The ASAS-3 database has two detections of a source at the above position on 2009 March 17 and 21 at  $V = 12.9$  suggesting the object is a dwarf nova. Follow-up spectroscopy by N. Masetti (private comm.) revealed a spectrum characteristic of a non-magnetic cataclysmic variable. Time series photometry reported in vsnet-alert<sup>6</sup> #14161, #14164, #14165, and #14210 suggested a presence of 0<sup>d</sup>.32 unstable periodic modulation.

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<sup>4</sup><http://www.cbat.eps.harvard.edu/unconf/followups/J17452791-2305213.html>

<sup>5</sup>[http://stereo.gsfc.nasa.gov/~thompson/nova\\_sagittarii\\_2012/](http://stereo.gsfc.nasa.gov/~thompson/nova_sagittarii_2012/)

<sup>6</sup><http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert>

**XMMSL1 J014956.7+533504.** A  $V = 12.8$  transient was detected on 2012 January 29 at 01:49:56.77 +53:35:01.8 ( $\pm 0'.5$ , J2000, Korotkiy & Sokolovsky 2012a) coinciding with an X-ray source listed in the XMM-Newton slew survey catalog XMMSL1 J014956.7+533504 (Saxton et al. 2008). Spectroscopy by A. Arai, M. Nagashima, C. Naka (Kyoto Sangyo Univ.) reported through TOCP<sup>7</sup> revealed that the flare is a dwarf nova outburst.

**Image archive.** The images obtained within the NMW survey are available at the project's webpage<sup>8</sup>. The archive server is written in Haskell functional programming language with Yesod web framework by one of the authors (AL) and is using SWarp (Bertin et al. 2002) for fast image resampling. The archive of photometric measurements is currently under development.

#### 4. Summary

We developed and tested the NMW system capable of detecting optical transients near the Galactic plane down to  $V < 13.5$  hours after they appear. The design is based on relatively cheap mass-produced components and open source image analysis software (partly developed by us), so similar transient-search systems can be easily deployed elsewhere. Construction of an automated clam-shell or dome-type enclosure is required to put our system on constant alert. The first survey results include the discovery of Nova Sgr 2012 No. 1 and two X-ray emitting cataclysmic variables 1RXS J063214.8+25362 and XMMSL1 J014956.7+533504. A web-accessible image and photometry archive is being developed to ensure full use of collected data.

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<sup>7</sup><http://www.cbat.eps.harvard.edu/unconf/followups/J01495677+5335018.html>

<sup>8</sup><http://scan.sai.msu.ru/nmw/>

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